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Field Assessment of Inverted Humus Mounds Produced by Three Site Preparation Implements in North Central British Columbia

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Field Assessment of Inverted Humus Mounds Produced by Three Site Preparation Implements in North Central British Columbia

by
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ABSTRACT

As part of Forest Resources Development Agreement (FRDA) Project 1.10, a series of site-preparation trials was established by the British Columbia Ministry of Forests and Lands (MOFL) and the Canadian Forestry Service (CFS). The Forest Engineering Research Institute of Canada (FERIC) conducted field assessments of inverted humus mounds produced by three implements, as part of this trial. The Sinkkilä HMF scarifier, MOFL mounder (Ministry mounder), and Bräcke mounder were used on four locations in northern British Columbia. In September 1986, FERIC measured mound configuration (mineral capping, height, length, and width) and compared the results for each machine and location.

Overall, the Ministry mounder had the greatest success in producing inverted mounds on all four locations. It had the highest percentage of acceptable mounds of the three machines (79-95%), and mineral-soil capping was consistently greater than 10 cm.

The Sinkkilä HMF scarifier was inconsistent in its results. It performed well at Dawson Creek (80% acceptable mounds) but poorly at Mackenzie (44% acceptable mounds). The unsatisfactory performance at Mackenzie was due in part to mechanical malfunction.

The Bräcke mounder was consistent in its overall performance on all three locations, with 70-80% acceptable mounds. However, the ability of the machine to prepare mounds with greater than 10 cm mineral-soil capping was definitely dependent on, and limited by, the site.

The post-winter reassessment planned for May-June 1987 will demonstrate how these mounds change over the winter season. Subsequent biological assessments under FRDA projects will demonstrate which mound types are most beneficial to seedling survival and growth. This information will assist foresters in developing site-specific mineral-capping prescriptions, in correlating post-treatment and pre-planting mound configurations, and in choosing suitable site preparation implements.

Keywords: site preparation, inverted humus mounds, mounding, Bräcke, Sinkkilä, MOFL mounder

PREFACE

This study was funded jointly by the Forest Resources Development Agreement (FRDA) and the Forest Engineering Research Institute of Canada (FERIC). The study was carried out in cooperation with FRDA Research Project 1.10. A mound assessment procedure was developed for the Sinkkilä HMF scarifier evaluation (also part of FRDA 1.10) with input from Canadian Forestry Service (CFS), B.C. Ministry of Forests and Lands (MOFL), and FERIC. This procedure was then modified to suit the specific needs of this study.

The author is grateful for the assistance provided by R.G. McMinn (consultant), Victoria; M. Grismer (CFS), L.R. Bedford (FRDA 1.10 Project Leader), J. Thornton and W. Bergerud (MOFL, Victoria); and A. MacKinnon (MOFL, Prince George); for the cooperation from MOFL Forest District personnel in Fort St. John, Dawson Creek, Mackenzie, and Vanderhoof; and for assistance in field work, data analysis, and report preparation by FERIC personnel A. Alger, P.D. Forrester, J. Breadon, K. Francoeur, and D. Miller.

TABLE OF CONTENTS

ABSTRACT iii

PREFACE iv

1 INTRODUCTION 1

2 DESCRIPTION OF MOUNDING EQUIPMENT 2

2.1 The Sinkkilä HMF scarifier 2
2.2 The Ministry mounder 3
2.3 The Bräcke mounder 4

3 DESCRIPTION OF SITES 5

3.1 Fort St. John 5
3.2 Dawson Creek 5
3.3 Mackenzie 5
3.4 Vanderhoof 5

4 MOUND ASSESSMENT PROCEDURE 8

5 MOUND ASSESSMENT RESULTS 9

5.1 Mound Classes 9
5.1.1 Machines 9
5.1.2 Locations 13
5.2 Mound Dimensions 13
5.2.1 Machines 13
5.2.2 Locations 21
5.2.3 Analysis of mound height by mound class 21
5.3 Ground Contact 22
5.4 Reasons for Poor Mound Formation 22
5.5 Left and Right Shovels—Bräcke mounder 25

6 SUMMARY AND CONCLUSION 26

7 LITERATURE CITED 28

APPENDICES

1 Manufacturers and distributors of mounding equipment 29
2 Contingency table analysis 30
3 Comparison of left and right shovels—Bräcke mounder 38

TABLES

1 Characteristics of treatment sites 7
2 Number of mound attempts assessed—fall 1986 8
3 Date of treatment and assessment 9
4 Distribution of mound classes—Sinkkilä 10
5 Distribution of mound classes—Ministry mounder 11
6 Distribution of mound classes—Bräcke mounder 12
7 Comparison of mounding success 13
8 Average mound dimensions of acceptable mounds—Sinkkilä 19
9 Average mound dimensions of acceptable mounds—Ministry mounder 20
10 Average mound dimensions of acceptable mounds—Bräcke mounder 21
11 Ground contact within acceptable mound classes 22
12 Reasons for poor mound formation—Sinkkilä 23
13 Reasons for poor mound formation—Ministry mounder 24
14 Reasons for poor mound formation—Bräcke mounder 25
15 Summary of performance for three mounding implements 26

FIGURES

1 Stylized inverted humus mound 1
2 The Sinkkilä HMF scarifier 2
3 The Ministry mounder 3
4 The Bräcke mounder 4
5 Location of the four study areas 6

PLATES

1 Sinkkilä HMF scarifier, Fort St. John 15
2 Sinkkilä HMF scarifier, Dawson Creek 15
3 Sinkkilä HMF scarifier, Dawson Creek 15
4 Sinkkilä HMF scarifier, Mackenzie 15
5 Sinkkilä HMF scarifier, Mackenzie 16
6 Ministry mounder, Fort St. John 16
7 Ministry mounder, Dawson Creek 16
8 Ministry mounder, Mackenzie 16
9 Ministry mounder, Vanderhoof 17
10 Ministry mounder, Fort St. John 17
11 Ministry mounder, Vanderhoof 17
12 Bräcke mounder, Fort St. John 17
13 Bräcke mounder, Dawson Creek 18
14 Bräcke mounder, Fort St. John 18
15 Bräcke mounder, Dawson Creek 18
16 Bräcke mounder, Mackenzie 18

1 INTRODUCTION

As part of Forest Resources Development Agreement (FRDA) Project 1.10, a series of site-preparation trials was established by the British Columbia Ministry of Forests and Lands (MOFL) and the Canadian Forestry Service (CFS), Pacific Forestry Centre (PFC). These trials were located in four areas and consisted of mechanical, herbicide, and fertilizer treatments. Monitoring of ecophysiological characteristics as seedling establishment progresses is planned over the remaining 3-year term of the project.

One of the treatment options on these areas is the formation of inverted humus mounds (Figure 1). Three implements, the Sinkkilä HMF scarifier, the MOFL-developed mounder (Ministry mounder), and the Bräcke mounder, were used in the trials to produce this mound configuration. The equipment and the sites are described more fully in Sections 2 and 3.

In the fall of 1986, the Forest Engineering Research Institute of Canada (FERIC) conducted field assessments of the inverted humus mounds under contract to MOFL, funded in part by FRDA. The project objective was to compare the effectiveness of the three site preparation implements in producing mounds, and to describe the configuration of mounds produced by each. This fall assessment was the first of two assessments, with the second planned for spring 1987. The spring assessment will determine the effects of winter settling on mound size, form, and composition.

This report summarizes the results of the fall evaluations. The equipment and sites are described briefly. Summaries of the measurement results and mound descriptions are presented, and analysis of equipment and location differences are described.

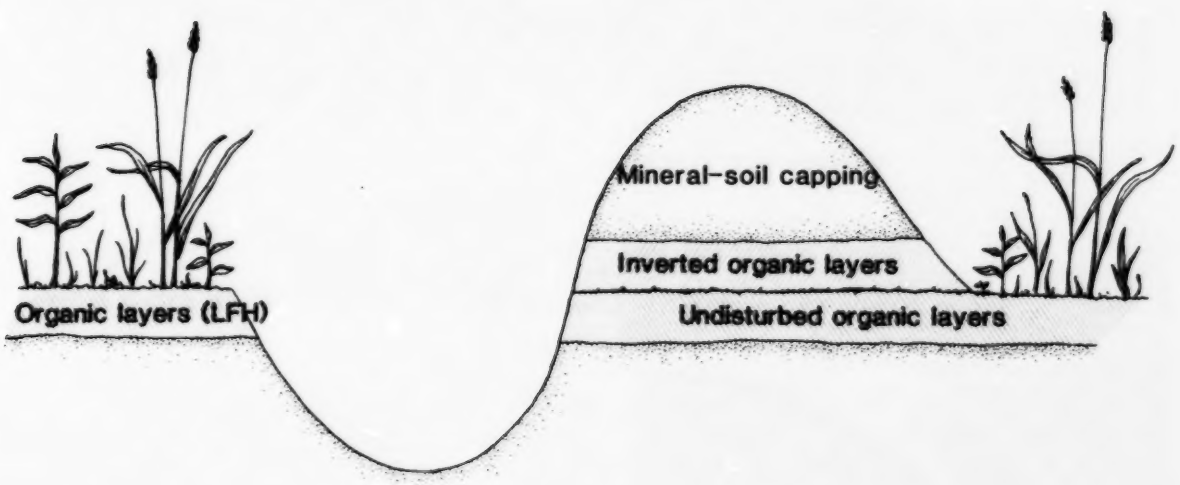

FIGURE 1. Stylized inverted humus mound.

2 DESCRIPTION OF MOUNDING EQUIPMENT

A brief description of each of the site preparation implements follows. More details can be obtained from the sources referenced in Appendix 1, from the author, or from Coates and Haeussler (1984).

2.1 The Sinkkilä HMF scarifier

The Sinkkilä HMF scarifier is a modified version of earlier machines used in Finland for patch scarification. It is manufactured by Teraskomponentti Ky in Finland and distributed by Canadian Forestry Equipment Ltd. The unit used in 1986 in British Columbia, owned by Forest Lease Inc., is the first in Canada. The machine was mounted on a John Deere 740 skidder and consists of two scarifier units, 2 m apart, each with four pairs of rippers (Figure 2). Mounds, scalps, or continuous shallow furrows can be produced, depending upon the angle of the ripper and the hydraulic braking applied to it. When the machine is mounding, the brake is applied to the ripper wheel at its shallowest angle. The ripper is drawn through the organic material, and into the mineral soil. When the brake is released, the ripper rotates; the organic/mineral-soil accumulation overturns and a mound is formed. Length of braking time can be set for options in mound size and for variations in soil condition. The Sinkkilä does not have any powered functions. It operates with its own hydraulic assembly and from a 24-volt battery series shared with the skidder. The scarifier was leased and operated by Arboress Enterprises Ltd. of Prince George.

FIGURE 2. The Sinkkilä HMF scarifier. Note the angled rippers.

2.2 The Ministry mounder

The Ministry mounder has been developed by the Silviculture and Engineering branches of MOFL over the past 6 years. The prototype used in 1986 for the sites described in this paper was mounted on a Cat D7E crawler, equipped with flotation tracks and a V-blade. Digging buckets are mounted on the ripper parallelogram of the machine (Figure 3). The hydraulics of the crawler drive the site preparation unit. Hydraulic pressure is applied, driving the buckets into the ground while the machine is moving forward. The buckets are raised and then flipped to produce the overturned mineral mound over inverted organic material. The hydraulic pressure can be adjusted to suit the soil conditions and the desired mound configuration. As well, digging cycle and spacing can be set using the onboard computer controls. Distance between shovels is 2 m. The equipment is owned by MOFL.

FIGURE 3. The Ministry mounder. The left shovel in the inset is in the flipped position and the right is in the dig configuration. This unit is a prototype and more compact in its current design.

2.3 The Bräcke mounder

The Bräcke mounder is an adaptation of the Bräcke cultivator used in Scandinavia and Canada for patch scarifying. The machine is manufactured by Robur Maskin AB in Sweden and distributed in Canada by KBM Forestry Consultants Inc. The Bräcke mounder consists of two units housed in box frames, mounted on a drawbar frame. Each unit is composed of a rubber tire and a mattock wheel (Figure 4). The Bräcke cultivator most commonly has four pairs of mattocks per mattock wheel. The Bräcke mounder used on these trials was a three-mattock unit. A chain mechanism links the rubber tire and the mattock wheel through a gearbox. As the rubber tire revolves, the mattock wheel also rotates, at a slower speed, and the mattocks move through the soil. This produces a scalp and inverted accumulation. Length of patch and distance between patches along the row can be varied by altering the gear ratios in the chain mechanism. Distance between the mattocks was 2.0 m. The Bräcke mounder has the additional ability to produce mineral caps on the organic overturns. The tined shovels dig into the scalp provided by the mattock wheels and deposit additional mineral soil on the mound as the shovels lift.

The shovel mechanism behind the mattocks is driven hydraulically by the self-contained hydraulic system with auxilliary engine mounted on the frame. Modifications to the shovel mechanism have been tested over the past 2 years of use. The length of cam, angle of shovel penetration, and shovel shape were altered in attempts to improve mounding height.[1] During the FRDA trials, the prime mover was a Clark 668 skidder. This equipment was owned and operated by Integrated Silviculture Services Ltd. of Prince George.

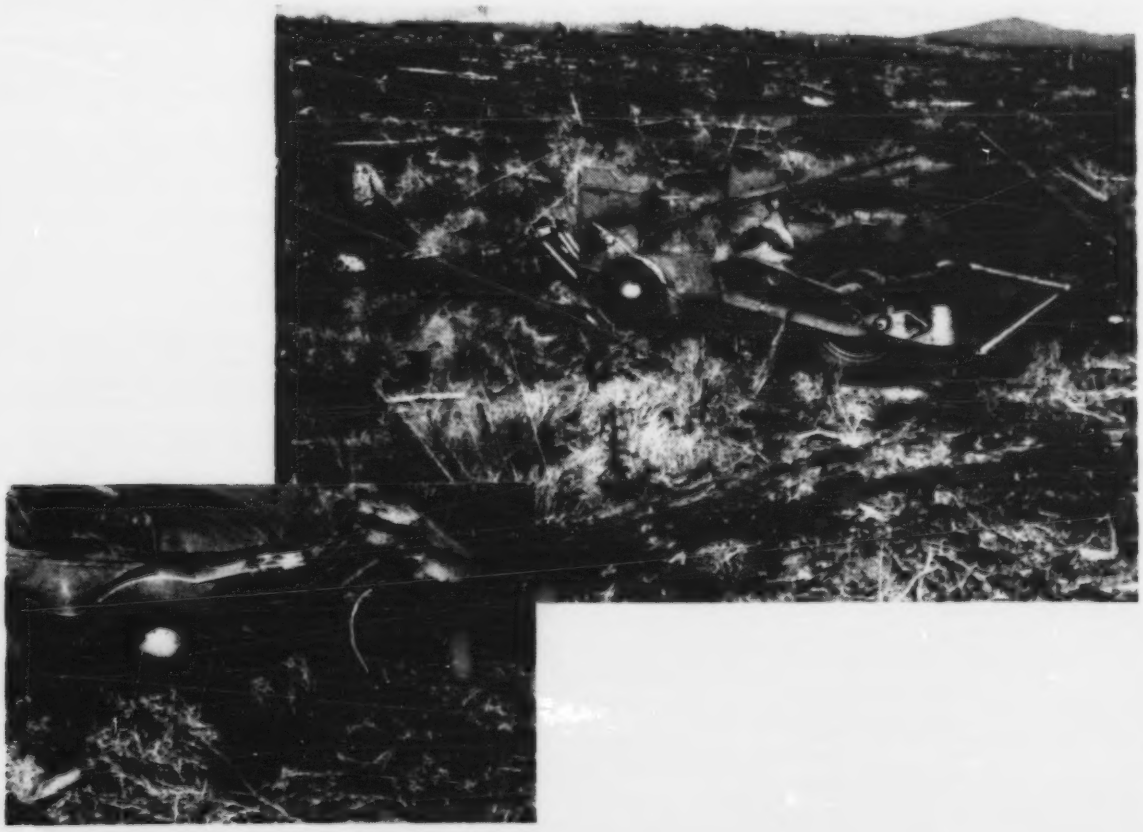

FIGURE 4. The Bräcke mounder. There are three mattocks on this unit compared to the more common four on the Bräcke cultivator.

[1] Parolin, R.W. 1986. Upper-Halfway trials of Bräcke mounder. Industrial Forestry Service Ltd., Prince George. Unpublished report. 15 p.

3 DESCRIPTION OF SITES

Four locations were chosen by MOFL and CFS to test the treatment options during summer 1986. These sites were considered representative of areas where stand establishment has been hampered by cold moist soils and vegetative competition. The study site locations, shown in Figure 5, were near Fort St. John, Dawson Creek, Mackenzie, and Vanderhoof. Table 1 summarizes the ecological classification and soil characteristics of the four sites.[2]

3.1 Fort St. John

The Fort St. John site was located at Iron Creek, northwest of Fort St. John. The site is in the Halfway River Moist Cold Southern Boreal White and Black Spruce variant (BWBSd2) (A. MacKinnon, pers. comm., 1987). The soil was fine textured, silty clay loam and clay loam (according to Pojar). The area was selectively logged in 1966; clearcut in 1974; and windrow scarified in winter 1985.

3.2 Dawson Creek

The Dawson Creek site was located 60 km west of Dawson Creek, in the Stewart Lake area. The site was in the Dawson Creek Moist Cool Southern Boreal White and Black Spruce variant (BWBSc1) (Jang *et al.* 1986). Soils were somewhat coarser textured than in Fort St. John, with sandy and clay loams. The area had been selectively logged several times in the past 30 years and was burned in the mid-1960's and in 1971. The aspen on the area had been sheared and windrowed during April 1986.

3.3 Mackenzie

The Mackenzie site was located 5 km east of Mackenzie. It had been logged in winter 1977 and chain-dragged in 1978. The area was variable, within the Fraser Basin Moist Cool Central Sub-Boreal Spruce variant (SBSj2) (DeLong *et al.* 1985), but composed of three associations within that (Table 1). Soils ranged from sandy silt to silty loam. As well, humus depth and rooting depth were variable. The brush, grass, and aspen on this site were more typical of a post-logging situation than the brush-bladed Fort St. John and Dawson Creek sites.

3.4 Vanderhoof

The Vanderhoof site was located 75 km southwest of Vanderhoof, along the Kluskus Road. The site was within the Moist Cold Central Sub-Boreal Spruce subzone (SBSi) (DeLong *et al.* 1986). The soils were very compact, with 5-30% coarse fragments on the sampled locations. Humus depth was 2-8 cm, and rooting depth ranged from 7 to 15 cm. This shallow rooting depth was likely a result of the compact features of the soil. The area had been summer and winter logged in 1977 with a full-tree feller-buncher/ grapple-skidder system. The Ministry mounder was the only mounding equipment used on this site. Its downpressure capability was judged necessary for successful mounding in these compacted and stony soils.

[2] MOFL staff described the ecological classification and vegetation and soil characteristics at five control plots at each location.

FIGURE 5. Location of the four study areas.

TABLE 1. Characteristics of treatment sites
This information is a summary of control plot descriptions, at each location, by MOFL

Location	Ecological classification	Humus form[a]	Humus depth (cm)	Soil texture	Soil moisture	Coarse fragments
Fort St. John	Moist Cold Southern Boreal White and Black Spruce BWBSd2 variant 06 Association - White Spruce - Horsetail (05 Association - Highbush-cranberry - Tall Bluebells)	moder (mor)	11-14 (7)	silty clay loam (clay loam)	subhygric (hygric, mesic)	<5%
Dawson Creek	Moist Cool SouthernBoreal White and Black Spruce BWBSc1 variant 05 Association - Highbush-cranberry - Oak Fern (06 Association - Highbush-cranberry - Tall Bluebells) (07 Association - Spruce - Horsetail)	moder	14-18 (8)	sandy loam, clay loam	subhygric (hygric)	<2%
Mackenzie	Moist Cool Central Sub-Boreal Spruce SBSj2 variant 01 Association - Black Gooseberry - Oak Fern 03 Association - Black Huckleberry - Bunchberry (04 Association - Devil's Club - Oak Fern)	mor (moder)	1-2 (10,16)	sandy silt, silty sand (silt loam)	mesic (submesic) subhygric)	<2%
Vanderhoof	Moist Cold Central Sub-Boreal Spruce SBSi subzone 01 Association - Prickly Rose - Colt's-foot	mor (moder)	2-8	silt loam	mesic	10% (20%, 30%)

[a] Bracketed descriptions are minor components of the site.

4 MOUND ASSESSMENT PROCEDURE

Within each location, the treatments had been assigned in a randomized block design. Treatment plots within each of the five blocks were 36 x 25 m, and were designed to hold 80 trees at planting time. Plots mechanically treated with mounding equipment contained four machine passes each. For the purposes of sampling for this assessment, each pass was considered a transect of 20 mounds, 10 with the right implement and 10 with the left. Therefore, for each location and machine there was a total of 20 transects. These were numbered and an initial sample of 10 were drawn. Additional transects were sampled as required to meet the criteria of plus or minus 20% of the mean numbers of mounds in acceptable classes, with 90% confidence. The number of mound attempts assessed at each location for each machine is shown in Table 2. Table 3 lists the dates of treatment and assessment for each.

At each mound attempt location, the following parameters were measured:

1. mound class (average depth of mineral capping determined from shovel probes or description of attempt);
2. mound length and width to the nearest 10 cm;
3. mound height to the nearest centimetre;
4. contact between the mound and the ground; and
5. assessed cause of poor mound formation.

As well, most acceptable mounds were staked and tagged for remeasurement the following spring. Photographs were taken of representative mounds for demonstration and re-evaluation purposes (Plates 1-16).

More details on the mound assessment procedure can be obtained from the author or Lorne Bedford, MOFL.

TABLE 2. Number of mound attempts assessed—fall 1986

Machine	Location				
	Fort St. John	Dawson Creek	Mackenzie	Vanderhoof	Total
Sinkkilä	200	200	400	N/A	800
Ministry mounder	200	196	200	200	796
Bräcke mounder	220	200	220	N/A	640
Total	620	596	820	200	2236

TABLE 3. Date of treatment and assessment

	Treatment dates	Assessment dates
Fort St. John		
Sinkkilä	July 2, 1986	October 7-9, 1986
Ministry mounder	July 30, 1986	October 7-9, 1986
Bräcke mounder	July 5, 1986	October 7-9, 1986
Dawson Creek		
Sinkkilä	July 4, 1986	September 25-29, 1986
Ministry mounder	September 11, 1986	September 25-29, 1986
Bräcke mounder	July 3, 1986	September 25-29, 1986
Mackenzie		
Sinkkilä	September 9, 1986	October 1-3, 1986
Ministry mounder	September 12 & 18, 1986	October 1-3, 1986
Bräcke mounder	July 6, 1986	October 1-3, 1986
Vanderhoof		
Ministry mounder	September 20, 1986	October 4-5, 1986

5 MOUND ASSESSMENT RESULTS

5.1 Mound Classes

Mineral-soil capping 3 cm and greater or well-decomposed organic material 5 cm and greater, over an inverted organic layer, were considered acceptable mound classes. The frequency of the mound classes, expressed as average number of attempts per 20-mound transect and percent of total mound attempts, are shown for the Sinkkilä (Table 4), the Ministry mounder (Table 5), and the Bräcke mounder (Table 6). The results were analyzed by contingency table methods and are presented in Table 7. The details of these analyses are in Appendix 2.

5.1.1 Machines

The Sinkkilä performed well at Fort St. John and Dawson Creek, with 82.0 and 79.5% of the mounds, respectively, in the acceptable mound classes. At Mackenzie, however, the results were poor, with less than 50% successful. Mechanical malfunctioning of the equipment was a major reason for this failure. Most failures fell within the "no mound" and "organic mound not inverted" categories. Contingency table analysis of the overall success of mounding showed there was a location difference when the Mackenzie treatment was included, but not when Fort St. John and Dawson Creek were analyzed alone. However, mound classes with greater than 10-cm mineral-soil capping were more numerous at Dawson Creek than at Fort St. John.

The Ministry mounder was 79.0% successful at Fort St. John and over 90% successful at the other locations. The majority of the successful mounds had greater than 10-cm mineral-soil capping. The best results were obtained at the Dawson Creek site, with over 60% of the mounds having mineral capping 20 cm or greater. Contingency table analysis of the overall success of the mounding showed a location difference, due to the poorer results at the Fort St. John site. When mound classes with greater than 10-cm capping are separated in the comparison, an additional location difference between Dawson Creek and Vanderhoof is evident; Vanderhoof had significantly less mineral capping.

The Bräcke mounder was successful in 70% or more of the attempts assessed on all three sites. The best results were at Dawson Creek, where 70% of the attempts resulted in mounds with mineral capping of 6 cm or greater. Contingency table analysis of the overall success of the mounding showed no location difference. Generally, the mounds produced by this implement had less mineral capping than those of the Sinkkilä or Ministry mounder. When mound classes with greater than 10 cm capping are separated in the comparison, there is a significant difference between all three locations, with Dawson Creek having the deepest capping and Fort St. John the shallowest.

TABLE 4. Distribution of mound classes—Sinkkilä

Mound class	Fort St. John		Dawson Creek		Mackenzie[a]	
	Avg no. per transect	% of total	Avg no. per transect	% of total	Avg no. per transect	%of total
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer	0.1	0.5	0.6	3.0	0.1	0.4
14-19 cm mineral soil in cap over inverted organic layer	0.6	3.0	3.7	18.5	0.1	0.5
10-13 cm mineral soil in cap over inverted organic layer	3.6	18.0	6.2	31.0	0.6	2.9
6-9 cm mineral soil in cap over inverted organic layer	5.2	26.0	3.4	17.0	1.5	7.5
3-5 cm mineral soil in cap over inverted organic layer	4.8	24.0	1.8	9.0	2.2	11.0
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	2.1	10.5	0.2	1.0	4.4	22.0
Acceptable	16.4	82.0	15.9	79.5	8.9	44.3
Less than or equal to 2 cm mineral soil in cap over inverted organic layer	0.1	0.5	0.5	2.5	0.2	1.0
Less than 5 cm well-decomposed inverted organic layer over undisturbed organic	0	0	0	0	0.1	0.4
Inverted organic mound	1.3	6.5	0.3	1.5	1.1	5.9
Organic mound, not inverted	0.7	3.5	1.6	8.0	5.3	26.5
Organic over mineral, not inverted	0	0	0.1	0.5	0	0
Vertical mound, not overturned	0.3	1.5	0.3	1.5	1.4	6.9
no mound	1.2	6.0	1.3	6.5	3.0	15.0
Unacceptable	3.6	18.0	4.1	20.5	11.1	55.7
Total	20.0	100.0	20.0	100.0	20.0	100.0

Averages and percentages are calculated from original data and therefore there may be discrepancies because of rounding.
[a] Poor performance on this site was due in part to failure of the hydraulic braking on the ripper.

TABLE 5. Distribution of mound classes—Ministry mounder

Mound class	Fort St. John		Dawson Creek		Mackenzie		Vanderhoof	
	Avg no. per transect	% of total	Avg no. per transect	% of total	Avg no. per transect	% of total	Avg no. per transect	% of total
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer	5.0	25.0	12.7	63.3	9.3	46.5	3.1	15.5
14-19 cm mineral soil in cap over inverted organic layer	4.2	21.0	3.9	19.4	3.7	18.5	4.3	21.5
10-13 cm mineral soil in cap over inverted organic layer	3.2	16.0	1.3	6.6	2.7	13.5	5.5	27.5
6-9 cm mineral soil in cap over inverted organic layer	1.6	8.0	0.8	4.1	1.1	5.5	3.6	18.0
3-5 cm mineral soil in cap over inverted organic layer	0.4	2.0	0.2	1.0	0.6	3.0	1.8	9.0
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	1.4	7.0	0.1	0.5	1.2	6.0	0	0
Acceptable	15.8	79.0	19.0	94.9	18.6	93.0	18.3	91.5
Less than or equal to 2 cm mineral soil in cap over inverted organic layer	0	0	0	0	0.1	0.5	0	0
Mineral cap over mineral soil	0	0	0	0	0.1	0.5	0	0
Inverted organic mound	0.5	2.5	0	0	0.5	2.5	0.3	1.5
Organic mound, not inverted	1.1	5.5	0.1	0.5	0.2	1.0	0.6	3.0
Mineral over undisturbed organic	0.7	3.5	0.6	3.1	0.1	0.5	0	0
Organic over mineral, not inverted	0	0	0	0	0.1	0.5	0	0
Vertical mound, not overturned	0.7	3.5	0.2	1.0	0	0	0	0
No mound	1.2	6.0	0.1	0.5	0.3	1.5	0.8	4.0
Unacceptable	4.2	21.0	1.0	5.1	1.4	7.0	1.7	8.5
Total	20.0	100.0	20.0	100.0	20.0	100.0	20.0	100.0

Averages and percentages are calculated from original data and therefore there may be discrepancies because of rounding.

TABLE 6. Distribution of mound classes—Bräcke mounder

Mound class	Fort St. John		Dawson Creek		Mackenzie	
	Avg no. per transect	% of total	Avg no. per transect	% of total	Avg no. per transect	% of total
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer	0.1	0.5	0.1	0.5	0	0
14-19 cm mineral soil in cap over inverted organic layer	0.2	0.9	2.3	11.5	0.7	3.6
10-13 cm mineral soil in cap over inverted organic layer	1.0	5.0	5.8	29.0	2.9	14.6
6-9 cm mineral soil in cap over inverted organic layer	5.1	25.5	5.9	29.5	3.8	19.1
3-5 cm mineral soil in cap over inverted organic layer	6.2	30.9	1.8	9.0	4.9	24.5
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	1.7	8.6	0	0	1.7	8.6
Acceptable	14.3	71.4	15.9	79.5	14.0	70.4
Less than or equal to 2 cm mineral soil in cap over inverted organic layer	0.2	0.9	0.4	2.0	0.3	1.4
Less than 5 cm well-decomposed inverted organic layer over undisturbed organic	0	0	0.1	0.5	0	0
Inverted organic mound	2.3	11.8	0.1	0.5	2.1	10.5
Organic mound, not inverted	1.5	7.7	0.6	3.0	1.2	5.9
Mineral over undisturbed organic	0.3	1.4	1.7	8.5	0.2	0.9
Vertical mound, not overturned	0	0	0.1	0.5	0.1	0.4
No mound	1.4	6.8	1.1	5.5	2.1	10.5
Unacceptable	5.7	28.6	4.1	20.5	6.0	29.6
Total	20.0	100.0	20.0	100.0	20.0	100.0

Averages and percentages are calculated from original data and therefore there may be discrepencies because of rounding.

TABLE 7. Comparison of mounding success

Overall success acceptable and unacceptable mound classes	Success in achieving deep mineral capping - ≥ 10 cm
BY MACHINE	
INCREASING SUCCESS→	INCREASING SUCCESS→
1. Sinkkilä Mackenzie Dawson Creek Fort St. John	1. Sinkkilä Mackenzie Fort St. John Dawson Creek
2. MINISTRY mounder Fort St. John Vanderhoof Mackenzie Dawson Creek	2. MINISTRY mounder Fort St. John Vanderhoof Mackenzie Dawson Creek
3. Bräcke mounder Fort St. John Mackenzie Dawson Creek	3. Bräcke mounder Fort St. John Mackenzie Dawson Creek
BY SITE	
INCREASING SUCCESS→	INCREASING SUCCESS→
1. FORT ST. JOHN Bräcke mounder Ministry mounder Sinkkilä	1. FORT ST. JOHN Bräcke mounder Sinkkilä Ministry mounder
2. DAWSON CREEK Sinkkilä Bräcke mounder Ministry mounder	2. DAWSON CREEK Bräcke mounder Sinkkilä Ministry mounder
3. MACKENZIE Sinkkilä Bräcke mounder Ministry mounder	3. MACKENZIE Sinkkilä Bräcke mounder Ministry mounder

Machines or locations underlined with the same line are not statistically different to 95% confidence.

5.1.2 Locations

When locations are examined individually and machines compared, contingency table analysis showed that, overall, the Sinkkilä and Ministry mounder performed similarly at Fort St. John while the Bräcke mounder had significantly fewer acceptable mounds. When depth of capping is considered (greater than 10 cm), there are significant differences between all three machines, with the Ministry mounder having the deepest capping and the Bräcke mounder the shallowest.

At Dawson Creek, the Sinkkilä and Bräcke mounder performed similarly, with the Ministry mounder producing significantly greater numbers of acceptable mounds. This remains true when depth of mineral capping is considered as well.

The results with all three implements were significantly different at Mackenzie, with the Ministry mounder giving the best performance and the Sinkkilä the poorest. This relationship remains, even when depth of capping is considered.

5.2 Mound Dimensions

The average mound dimensions, height and area, are shown in Table 8 for the Sinkkilä, Table 9 for the Ministry mounder, and Table 10 for the Bräcke mounder. Mound area is calculated from length and width measurements, which were recorded in the field to the nearest 10 cm.

5.2.1. Machines

The Sinkkilä did not appear to have much variation in overall average height of acceptable mound at Fort St. John and Mackenzie. The highest and largest mounds were found at Dawson Creek. At Fort St. John, the mounds tended to be smaller in area than at the other sites. Although the success rate at Mackenzie was poor, the acceptable mounds were intermediate in size in relation to the other areas.

The Ministry mounder showed little difference in average mound height at the first three sites (35 cm), but height was greatly reduced at Vanderhoof (27 cm). This reflects the different soil conditions encountered on that site. As with the Sinkkilä, the smallest overall mound area occurred at Fort St. John, and the largest at Dawson Creek. The mounds formed by the Ministry mounder at Dawson Creek had the largest area encountered at all locations and for all machines. The Vanderhoof mounds were larger in area than those at Fort St. John, although they were less high.

The same trends occurred with the Bräcke mounder. Overall mound height was similar for the three sites, but mound area was greatest for Dawson Creek and least for Fort St. John. Generally, mound height averaged 25 cm for the larger mineral capping classes and 20 cm for the smaller cappings.

The trends between machines show the Ministry mounder produces generally higher and larger mounds than the Sinkkilä. These two pieces of equipment produced mounds 50% higher and 30-100% larger than the Bräcke mounder. Analysis of variance (ANOVA)[3] of mound height showed all the machines were significantly different.

[3] Details of the analysis of variance will be included in the final report following Spring 1987 field assessment.

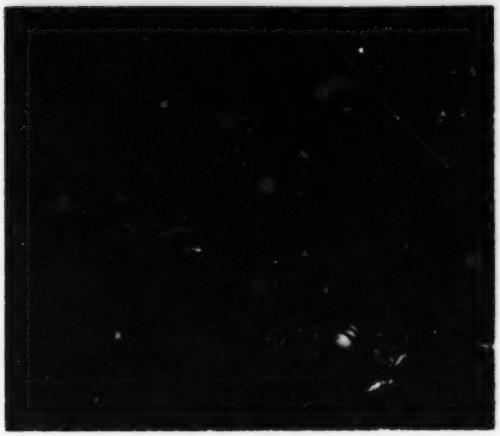

PLATE 1. Sinkkilä HMF scarifier, Fort St. John. Class: greater than 20 cm mineral soil in cap over inverted organic layer. Mound dimensions: 30 (l) x 30 (w) x 40 cm (h).[a]

PLATE 2. Sinkkilä HMF scarifier, Dawson Creek. Class 10-13 cm mineral soil in cap over inverted organic layer. Mound dimensions: 30 (l) x 90 (w) x 35 cm (h).

PLATE 3. Sinkkilä HMF scarifier, Dawson Creek. Class: 6-9 cm mineral soil in cap over inverted organic layer. Mound dimensions: 50 (l) x 100 (w) x 54 cm (h).

PLATE 4. Sinkkilä HMF scarifier, Mackenzie. Class: greater than 5 cm well-decomposed inverted organic layer over undisturbed organic. Mound dimensions: 50 (l) x 50 (w) x 41 cm (h).

[a] l = length, w = width, h = height

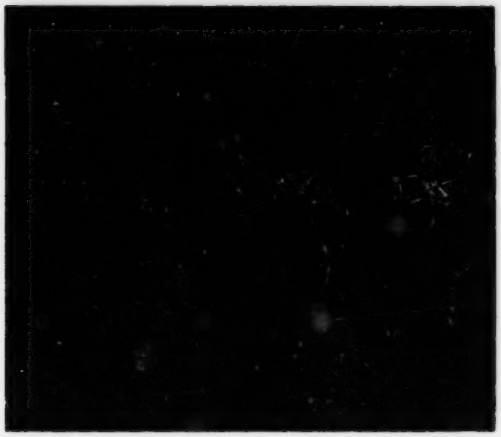

PLATE 5. Sinkkilä HMF scarifier, Mackenzie. Class: organic mound, not inverted. Likely reason for failure of mound was machine malfunction.

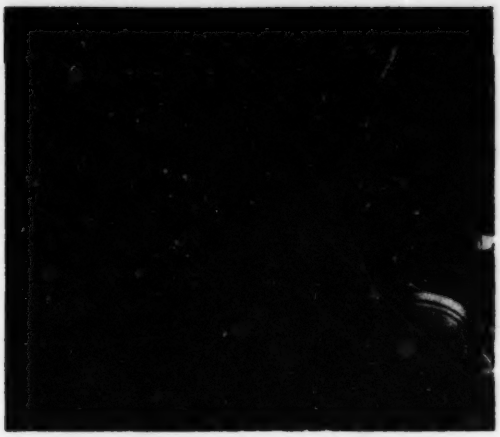

PLATE 6. Ministry mounder, Fort St. John. Class: greater than 20 cm mineral soil in cap over inverted organic layer. Mound dimensions: 60 (l) x 50 (w) x 50 cm (h). Note the steep sides and the cracks within the capping

PLATE 7. Ministry mounder, Dawson Creek. Class: greater than 20 cm mineral soil in cap over inverted organic layer. Mound dimensions: 80 (l) x 70 (w) x 40 cm (h).

PLATE 8. Ministry mounder, Mackenzie. Class: greater than 20 cm mineral soil in cap over inverted organic layer. Mound dimensions: 30 (l) x 30 (w) x 40 cm (h).

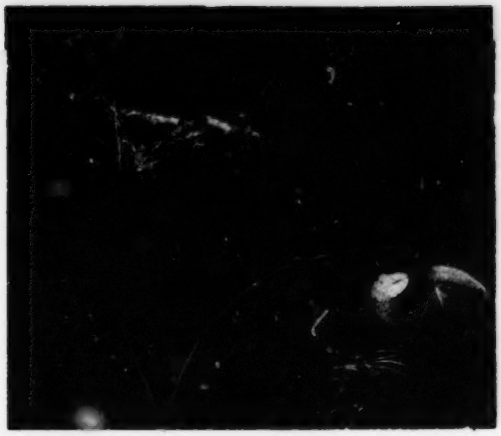

PLATE 9. Ministry mounder, Vanderhoof. Class: 6-9 cm mineral soil in cap over inverted organic layer. Mound dimensions: 50 (l) x 50 (w) x 38 cm (h).

PLATE 10. Ministry mounder, Fort St. John. Class: vertical mound, not overturned. No reason for failure of mound was apparent.

PLATE 11. Ministry mounder, Vanderhoof. Class: organic mound, not inverted. No reason for failure of mound was apparent.

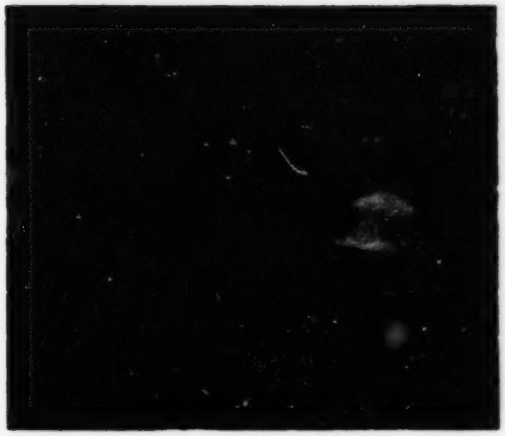

PLATE 12. Bräcke mounder, Fort St. John. Class: greater than 20 cm mineral soil in cap over inverted organic layer. Mound dimensions: 40 (l) x 40 (w) x 28 cm (h).

PLATE 13. Bräcke mounder, Dawson Creek. Class: 10-13 cm mineral soil in cap over inverted organic layer. Mound dimensions: 60 (l) x 60 (w) x 25 cm (h).

PLATE 14. Bräcke mounder, Fort St. John. Class: 6-9 cm mineral soil in cap over inverted organic layer. Mound dimensions: 30 (l) x 40 (w) x 20 cm (h).

PLATE 15. Bräcke mounder, Dawson Creek. Class: mineral soil over undisturbed organic layer. Likely reason for failure of mound was slash.

PLATE 16. Bräcke mounder, Mackenzie. Class: inverted organic mound. Note the decomposing slash material. Likely reason for failure of mound was slash.

TABLE 8. Average mound dimensions of acceptable mounds—Sinkkilä[a]

Mound class	Fort St. John		Dawson Creek		Mackenzie	
	Height cm	Area cm^2	Height cm	Area cm^2	Height cm	Area cm^2
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer			41	2067		
14-19 cm mineral soil in cap over inverted organic layer	35	3050	31	2549		
10-13 cm mineral soil in cap over inverted organic layer	32	1856	36	2295	31	2215
6-9 cm mineral soil in cap over inverted organic layer	31	1650	34	2048	29	1619
3-5 cm mineral soil in cap over inverted organic layer	30	1496	30	1428	28	1263
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	28	1114			34	2178
Overall	31	1626	34	2199	32	1872

[a] Dimensions shown only when sample size was greater than 5.

TABLE 9. Average mound dimensions of acceptable mounds—Ministry mounder[a]

Mound class	Fort St. John		Dawson Creek		Mackenzie		Vanderhoof	
	Height cm	Area cm^2	Height cm	Area cm^2	Height cm	Area cm^2	Height cm	Area cm^2
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer	44	1552	38	4017	37	2614	30	1829
14-19 cm mineral soil in cap over inverted organic layer	37	1564	35	3863	33	2389	25	2076
10-13 cm mineral soil in cap over inverted organic layer	33	1209	34	3692	36	2063	25	2113
6-9 cm mineral soil in cap over inverted organic layer	29	744	21	2033	31	1018	27	2594
3-5 cm mineral soil in cap over inverted organic layer					31	2150	28	1567
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	22	950			35	2933		
Overall	36	1328	36	3882	35	2397	27	2094

[a] Dimensions shown only when sample size was greater than 5.

TABLE 10. Average mound dimensions of acceptable mounds—Bräcke mounder[a]

Mound class	Fort St. John		Dawson Creek		Mackenzie	
	Height cm	Area cm^2	Height cm	Area cm^2	Height cm	Area cm^2
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer						
14-19 cm mineral soil in cap over inverted organic layer			26	1474	24	1500
10-13 cm mineral soil in cap over inverted organic layer	24	936	23	1912	24	1241
6-9 cm mineral soil in cap over inverted organic layer	21	889	20	1660	22	1339
3-5 cm mineral soil in cap over inverted organic layer	19	913	18	1824	21	1137
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	16	758			24	1328
Overall	20	890	22	1745	23	1257

[a] Dimensions shown only when sample size was greater than 5.

5.2.2 Locations

Analysis of variance of mound height did not show any significant differences for the Fort St. John, Dawson Creek, and Mackenzie locations. Vanderhoof was not included in the ANOVA because only one machine treated that site. As well, machine and location interactions were not found to be statistically significant.

5.2.3 Analysis of mound height by mound class

Analysis of variance of mound height was done for individual mound classes. Machine, location, and interaction differences were examined. Vanderhoof was again omitted from the analysis.

When mounds with greater than 20 cm of mineral soil capping were analysed, mounds at Fort St. John were significantly higher than at the other two sites.

The mound class with 14-19 cm mineral-soil capping showed a significant height difference between Fort St. John (with the highest mounds) and Dawson Creek, although Dawson Creek and Mackenzie were similar in this class. Also in this class, all three machines were significantly different, with the Ministry mounder producing the highest mounds and the Bräcke mounder the lowest.

The mound classes with 10-13 cm and 6-9 cm mineral-soil capping showed no significant difference in height due to location. In both classes, however, the Bräcke mounder had mounds significantly lower than either the Sinkkilä or the Ministry mounder. There was no significant difference between these last two machines.

5.3 Ground Contact

Table 11 presents the data for ground contact of the mounds for each machine and site. Overall there were very few instances of poor ground contact. Less than 4% of the mounds in acceptable classes were affected. The Sinkkilä at Mackenzie had the greatest number of mounds with poor contact, while the Fort St. John site had only one for all three machines.

The low slash conditions of the windrowed sites at Fort St. John and Dawson Creek provided few obstacles capable of interfering with contact between the inverted mound and the undisturbed surface. At Mackenzie and Vanderhoof there were more saplings and brush on-site. Because the Ministry mounder had a front-mounted V-blade, it was able to remove this vegetation before mounding. The Sinkkilä and Bräcke mounder did not have this option.

The time between treatment and assessment—in some cases up to 3 months—allowed settling of the mounds (Table 3). This may have reduced the observed incidence of poor ground contact, compared to that noted immediately after treatment.

TABLE 11. Ground contact within acceptable mound classes

	Fort St. John (no.)	Dawson Creek (no.)	Mackenzie (no.)	Vanderhoof (no.)
Sinkkilä				
Good ground contact	164	152	163	N/A
Poor ground contact	0	6	13	
Total	164	158	176	
Ministry mounder				
Good ground contact	158	180	183	181
Poor ground contact	0	6	3	2
Total	158	186	186	183
Bräcke mounder				
Good ground contact	156	154	150	N/A
Poor ground contact	1	4	5	
Total	157	158	155	

5.4 Reasons for Poor Mound Formation

The assessed reasons for poor mound formation are outlined for the Sinkkilä (Table 12), the Ministry mounder (Table 13), and the Bräcke mounder (Table 14). Generally, the reasons for poor ground contact were slash and brush, regardless of the site and machine.

Unacceptable mound classes resulted from a variety of site reasons: slash, stumps, brush, and roots. In some instances, no site reasons were obvious and the reason could only be assessed as machine malfunction or unknown. Because the assessor was not on site at the time of treatment, these reasons were only used when some physical factor could not be attributed as cause. Both the Ministry mounder and Bräcke mounder had occurrences of "cap not on invert" (poor positioning of mineral cap).

TABLE 12. Reasons for poor mound formation—Sinkkilä

	Acceptable mound class poor ground contact			Unacceptable mound class		
	No. occurrences	% of total in category	% of total mounds assessed	No. occurrences	% of total in category	% of total mounds assessed
Fort St. John						
Slash	0			9	25	5
Stump	0			7	19	3
Excessive litter	0			2	6	1
Root	0			9	25	5
Decomposing wood	0			4	11	2
Machine error	0			1	3	1
No reason apparent	0			4	11	2
Total Fort St. John	0			36	100	19
Dawson Creek						
Slash	4	100	2	9	25	5
Stump	0			4	11	2
Root	0			2	5	1
Decomposing wood	0			2	6	1
Machine error	0			4	11	2
No reason apparent	0			15	42	8
Total Dawson Creek	4	100	2	36	100	19
Mackenzie						
Slash	7	64	2	84	39	21
Stump	0			23	11	6
Brush	3	27	<1	29	13	7
Root	0			15	7	4
Decomposing wood	1	9	<1	13	6	3
Machine error	0			15	7	4
No reason apparent	0			38	17	10
Total Mackenzie	11	100	3	217	100	55

TABLE 13. Reasons for poor mound formation—Ministry Mounder

	Acceptable mound class poor ground contact			Unacceptable mound class		
	No. occurrences	% of total in category	% of total mounds assessed	No. occurrences	% of total in category	% of total mounds assessed
Fort St. John						
Slash	0			2	5	1
Stump	0			8	20	4
Root	0			12	29	6
Decomposing wood	0			1	2	1
Cap not on invert	0			2	5	1
Machine error	0			4	10	2
No reason apparent	0			12	29	6
Total Fort St.	0			41	100	21
Dawson Creek						
Slash	1	33	<1	2	22	1
Rock				1	11	<1
Stump				1	11	<1
Decomposing wood	2	67	<1			
Cap not on invert				5	56	3
Total Dawson Creek	3	100	1	9	100	5
Mackenzie						
Slash	1	50	<1	3	27	2
Stump				5	46	3
Root	1	50	<1	1	9	1
Decomposing wood				2	18	1
Total Mackenzie	2	100	1	11	100	7
Vanderhoof						
Slash	2	100	1	4	24	2
Stump				7	41	3
Brush				2	12	1
Root				3	18	2
No reason apparent				1	5	1
Total Vanderhoof	2	100	1	17	100	9

TABLE 14. Reasons for poor mound formation—Bräcke mounder

	Acceptable mound class poor ground contact			Unacceptable mound class		
	No. occurrences	% of total in category	% of total mounds assessed	No. occurrences	% of total in category	% of total mounds assessed
Fort St. John						
Slash	0			7	11	3
Stump	0			5	8	2
Excessive litter	0			6	10	3
Root	1	100	0	7	11	3
Decomposing wood	0			12	20	5
Cap not on invert	0			6	10	3
No reason apparent	0			18	30	8
Total Fort St. John	1	100	0	61	100	27
Dawson Creek						
Slash	2	100	1	10	26	5
Stump	0			6	16	3
Brush	0			1	3	1
Root	0			2	5	1
Decomposing wood	0			3	8	1
Cap not on invert	0			7	18	4
No reason apparent	0			9	24	5
Total Dawson Creek	2	100	1	38	100	20
Mackenzie						
Slash	1	25	<1	26	40	12
Stump	0			11	17	5
Brush	2	50	1	5	8	2
Root	0			7	11	3
Decomposing wood	1	25	<1	7	11	3
Cap not on invert	0			5	7	2
No reason apparent	0			4	6	2
Total Mackenzie	4	100	2	65	100	29

5.5 Left and Right Shovels—Bräcke mounder

The Bräcke mounder had a modified "flipping" shovel on the right side of the implement, designed to reduce the "grading" of the mound. When the shovel was raised in the flipped position, it was less likely to drag over the mound as the machine moved forward. The analysis of these two shovels did not show any significant difference (Appendix 3). The use of the three-mattock wheel, rather than the four mattocks, may have reduced the need for, and effectiveness of, the flipping modification.

6 SUMMARY AND CONCLUSION

The results of the mound assessment are summarized in Table 15.

Overall, the Ministry mounder had the greatest success in producing inverted humus mounds on all four sites. The percentage of acceptable mounds was the largest of the three machines, and the mineral-soil capping was consistently greater than 10 cm. On some sites, large mound size might be detrimental because of microclimate changes. The Ministry mounder's success was partly due to two factors: the downpressure that could be applied to the shovels, and the V-blade mounted in front of the prime mover.

TABLE 15. Summary of performance for three mounding implements

	% Acceptable mounds			
	Fort St. John	Dawson Creek	Mackenzie	Vanderhoof
Sinkkilä				
Mineral capping ≥10 cm	21.5	52.5	3.8	N/A
Other acceptable mounds	60.5	27.0	40.5	N/A
Total acceptable mounds	82.0	79.5	44.3	N/A
Ministry mounder				
Mineral capping ≥10 cm	62.0	89.3	78.5	64.5
Other acceptable mounds	17.0	5.6	14.5	27.0
Total acceptable mounds	79.0	94.9	93.0	91.5
Bräcke mounder				
Mineral capping ≥10 cm	6.4	41.0	18.2	N/A
Other acceptable mounds	65.0	38.5	52.2	N/A
Total acceptable mounds	71.4	79.5	70.4	N/A

There were two observations about the mound-formation of the Ministry mounder. First, in many instances the organic material was distributed along the sides of the trench as the bucket was drawn through the soil. This reduced the amount available for the mound. During assessment, if some organic material was included in the overturn, the mound was considered successful. Second, in some cases the V-blade removed organic material prior to mounding. Again, as long as some material remained, the mound was classified as successful.

The Ministry mounder does not overturn the soil material as a hinged unit,and consequently the four sides of the mound produced were often very steep. The effectiveness of this type of mound will be determined by follow-up monitoring of mound deterioration over time.

The Sinkkilä produced an inverted humus mound with a hinged organic layer. In some cases the organic material was bunched to form a "concertina" shape. Another configuration with this implement was a "jelly roll", created when the organic overturn rolled under and formed a spiral. These variations were not common, occurring only under certain soil and root mat conditions and ripper brake settings.

The Sinkkilä HMF scarifier had inconsistent results, with the most success at Dawson Creek and the least at Mackenzie. The mechanical malfunction that occurred at other locations was similar in appearance to site-caused releasing of the ripper brake, and could not be reliably isolated at Mackenzie.

The Bräcke mounder was consistent in its overall performance on all three sites. However, the ability of the machine to prepare mounds with greater than 10 cm mineral capping was definitely site-dependent and site-limited. To prepare mineral capping, the implement must place the shovel within mineral soil, accumulate the material, and position the resulting mineral-soil cap on the inverted organic material. Humus depth was therefore an important factor, in addition to slash, vegetation, and other site characteristics affecting the action of the mattocks and shovel.

The mounds formed by the Bräcke mounder were not as large or distinctive as those of the other machines. The two-step process did not always result in a precise deposition of mineral soil on organic invert. The invert itself was often a scraped accumulation of organic material, while the capping deposited by the shovel was frequently composed of both mineral and organic material. It was occasionally deposited as a single unit, but more typically as several deposits. If these were linked, they were described as one cap during assessment; if not, the largest accumulation was chosen and described. The Bräcke mounder would be limited as humus depth increased, sooner than the previous two. However, because of the narrow width of the mattocks and shovel, it appears to be able to function relatively well in a light concentration of stumps, saplings, and slash (Mackenzie).

The results of the ANOVA on mound height by class suggest the Bräcke mounder can produce mounds of equal mineral capping to the other implements, but with significantly lower mound height. This may be important on sites where drought and frost heaving become severe on elevated microsites.

For all machines the Fort St. John location produced the poorest results. This may be due to the heavier clay content of the soil (28-40%). Soils will be sampled more intensively in the spring evaluation to identify the critical factor on this site.

When these implements are used operationally, they must meet not only plantable-spots-per-hectare objectives but also cost-per-hectare objectives. Total cost of meeting silvicultural objectives must include the implement's hourly cost and productivity as well as the costs of prior treatment, such as windrowing. A more expensive, slower machine like the Cat D7 or D8, with V-blade and mounder may prove cost-effective compared to two-pass treatments. However, the reverse may also be true on easier sites. Where windrowing and mounding with a skidder can be carried out inexpensively in a two-pass treatment, the cost may be less than crawler-based one-pass site preparation. The overall MOFL target cost of $200/ha for mounding treatments under average conditions may be met with all three implements. At this time, only the Bräcke mounder can be considered operational, although all three give results showing good potential.

The post-winter assessment will indicate how these mounds change over the season. Subsequent biological assessments by FRDA Project 1.10 will determine which mound types are most beneficial to seedling survival and growth. Seedling and root growth will be monitored on a variety of sites, as will seedling nutrition and soil carbon/nitrogen ratios. Revegetation on the various treatments will be monitored to determine effectiveness in reducing vegetative competition. This information will assist foresters in developing site-specific, mineral-capping prescriptions, in correlating post-treatment and pre-planting conditions, and in choosing suitable site preparation implements.

7 LITERATURE CITED

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APPENDIX 1. Manufacturers and distributors of mounding equipment

Sinkkilä HMF scarifier

Manufacturer

Teraskomponentti Ky
Satalakatu 1
18100 Heinola
Finland

Distributor

Canadian Forestry Equipment Ltd.
17212 - 106 Avenue
Edmonton, Alberta
T5S 1H9
(403) 484-6687

Ministry of Forests and Lands mounder

Prototype developed by:

Silviculture Branch and Engineering Branch
B.C. Ministry of Forests and Lands
1450 Government Street
Victoria, B.C.
V8W 3E7
(604) 387-1191

Bräcke mounder

Manufacturer

Robur Maskin AB
S - 84060 Bräcke
Sweden

Distributor

KBM Forestry Consultants Inc.
360 Mooney Street
Thunder Bay, Ontario
P7B 5R4
(807) 344-0811

APPENDIX 2. Contingency table analysis

A. Acceptable and Unacceptable Mound Classes

Comparison of locations by machine

1. *Sinkkilä*

	Fort St. John	Dawson Creek	Mackenzie	Total
Acceptable	164 (125)	159 (125)	177 (250)	500
Unacceptable	36 (75)	41 (75)	223 (150)	300
Total	200	200	400	800

Calculated $Chi^2 = 113.955$ Test $Chi^2 = 5.991$ at 0.05
Reject H_o of independence.
Likely source of the difference is Mackenzie.
Compare Fort St. John and Dawson Creek.

	Fort St. John	Dawson Creek	Total
Acceptable	164 (161.5)	159 (161.5)	323
Unacceptable	36 (38.5)	41 (38.5)	77
Total	200	200	400

Calculated $Chi^2 = 0.402$ Test $Chi^2 = 5.991$ at 0.05
Accept H_o of independence.
Data from these two locations can be pooled.

	Pooled Fort St. John Dawson Creek	Mackenzie	Total
Acceptable	323 (250)	177 (250)	500
Unacceptable	77 (150)	223 (150)	300
Total	400	400	800

Calculated $Chi^2 = 113.686$ Test $Chi^2 = 5.991$ at 0.05
Reject H_o of independence.
There is a significant difference in populations due to location.

2. *Ministry mounder*

	Fort St. John	Dawson	Mackenzie	Vanderhoof	Total
Acceptable	158 (179)	186 (176)	186 (179)	183 (179)	713
Unacceptable	42 (21)	10 (20)	14 (21)	17 (21)	83
Total	200	196	200	200	796

Calculated $Chi^2 = 37.49$ Test $Chi^2 = 7.815$ at 0.05
Reject H_o of independence.
Likely source of difference is Fort St. John.
Compare Dawson Creek, Mackenzie, and Vanderhoof.

	Dawson Creek	Mackenzie	Vanderhoof	Total
Acceptable	186 (183)	186 (186)	183 (186)	555
Unacceptable	10 (13)	14 (14)	17 (14)	41
Total	196	200	200	596

Calculated $Chi^2 = 1.433$ Test $Chi^2 = 7.815$ at 0.05
Accept H_o of independence.
Data from these locations can be pooled.

	Fort St. John	Pooled Dawson Creek Mackenzie Vanderhoof	Total
Acceptable	158 (179)	555 (534)	713
Unacceptable	42 (21)	41 (62)	83
Total	200	596	796

Calculated $Chi^2 = 31.403$ Test $Chi^2 = 7.815$ at 0.05
Reject H_o of independence.
There is a significant difference due to location.

3. *Bräcke mounder*

	Fort St. John	Dawson Creek	Mackenzie	Total
Acceptable	157 (162)	159 (147)	155 (162)	471
Unacceptable	63 (58)	41 (53)	65 (58)	169
Total	220	200	220	640

Calculated $Chi^2 = 5.429$ Test $Chi^2 = 5.991$ at 0.05
Accept H_o of independence.
There is no significant location effect and the data can be pooled.

Comparison of machines by location

1. *Fort St. John*

	Sinkkilä	Ministry mounder	Bräcke mounder	Total
Acceptable	164 (154.5)	158 (154.5)	157 (170)	479
Unacceptable	36 (45.5)	42 (45.5)	63 (50)	141
Total	200	200	220	620

Calculated $Chi^2 = 7.290$ Test $Chi^2 = 5.991$ at 0.05
Reject H_o of independence.
Examination of the data suggests the Bräcke mounder may be the different population.

	Sinkkilä	Ministry mounder	Total
Acceptable	164 (161)	158 (161)	322
Unacceptable	36 (39)	42 (39)	78
Total	200	200	400

Calculated $Chi^2 = 0.574$ Test $Chi^2 = 5.991$ at 0.05
Accept H_o of independence.
There is no machine difference.

	Ministry mounder	Bräcke mounder	Total
Acceptable	158 (150)	157 (165)	315
Unacceptable	42 (50)	63 (55)	105
Total	200	220	420

Calculated $Chi^2 = 3.259$ Test $Chi^2 = 5.991$ at 0.05
Accept H_o of independence.
There is no significant machine difference.

	Sinkkilä	Bräcke mounder	Total
Acceptable	164 (153)	157 (168)	321
Unacceptable	36 (47)	63 (52)	99
Total	200	220	420

Calculated $Chi^2 = 6.412$ Test $Chi^2 = 5.991$ at 0.05
Reject H_o of independence.
There is a significant machine difference.

2. *Dawson Creek*

	Sinkkilä	Ministry mounder	Bräcke mounder	Total
Acceptable	159 (169)	186 (166)	159 (169)	504
Unacceptable	41 (31)	10 (30)	41 (31)	92
Total	200	196	200	596

Calculated $Chi^2 = 23.379$ Test $Chi^2 = 5.991$ at 0.05
Reject H_o of independence.
Clearly the Sinkkilä and Bräcke mounder have similar results and can be pooled.

	Sinkkilä & Bräcke mounder	Ministry mounder	Total
Acceptable	318 (338)	186 (166)	504
Unacceptable	82 (62)	10 (30)	92
Total	400	196	596

Calculated $Chi^2 = 23.379$ Test $Chi^2 = 5.991$ at 0.05
Reject H_o of independence.
At Dawson Creek there is a significant machine difference between the Ministry mounder and the other two implements.

3. *Mackenzie*

	Sinkkilä	Ministry mounder	Bräcke mounder	Total
Acceptable	177 (253)	186 (126)	155 (139)	518
Unacceptable	223 (147)	14 (74)	65 (81)	302
Total	400	200	220	820

Calculated $Chi^2 = 144.345$ Test $Chi^2 = 5.991$ at 0.05
Reject H_o of independence.
The difference between all three machines is great, resulting in a very high Chi^2. Testing the Ministry mounder and Bräcke mounder alone will ensure the correctness of the conclusion that all three machines produce significantly different results at this site.

	Ministry mounder	Bräcke mounder	Total
Acceptable	186 (162)	155 (179)	341
Unacceptable	14 (38)	65 (41)	79
Total	200	220	420

Calculated $Chi^2 = 35.981$ Test $Chi^2 = 5.991$ at 0.05
Reject H_o of independence.
At Mackenzie, the results from all three machines are significantly different.

B. Mineral Capping Depth

Comparison of location by machine

1. *Sinkkilä*

The results earlier have demonstrated a very strong difference at Mackenzie.

	Fort St. John	Dawson Creek	Total
≥10 cm capping	43 (74)	105 (74)	148
Other acceptable	121(87.5)	54 (87.5)	175
Unacceptable	36 (38.5)	41 (38.5)	77
Total	200	200	400

Calculated $Chi^2 = 51.949$ Test $Chi^2 = 9.488$ at 0.05
Reject H_o of independence.
When capping depth is considered, there is a significant difference between locations.

2. *Ministry mounder*

Fort St. John was significantly different in the previous analysis. To check if this difference has remained, compare Fort St. John and Vanderhoof.

	Fort St. John	Vanderhoof	Total
>10 cm capping	124 (125.5)	129 (126.5)	253
Other acceptable	34 (44)	54(44)	88
Unacceptable	42 (29.5)	17 (29.5)	59
Total	200	200	400

Calculated $Chi^2 = 15.238$ Test $Chi^2 = 12.592$ at 0.05
Reject H_o of independence.
There is a significant difference between Fort St. John and Vanderhoof.

	Dawson Creek	Mackenzie	Vanderhoof	Total
≥10 cm capping	175 (151)	157 (155)	129 (155)	461
Other acceptable	11 (31.5)	29 (31)	54 (31.5)	94
Unacceptable	10 (13.5)	14 (14)	17 (13.5)	41
Total	196	200	200	596

Calculated $Chi^2 = 39.558$ Test $Chi^2 = 12.592$ at 0.05
Reject H_o of independence.
Test Dawson Creek and Mackenzie.

	Dawson Creek	Mackenzie	Total
≥10 cm capping	175 (164)	157 (168)	332
Other acceptable	11 (20)	29 (20)	40
Unacceptable	10 (12)	14 (12)	24
Total	196	200	396

Calculated Chi^2 = 10.224 Test Chi^2 = 12.592 at 0.05
Accept H_o of independence, these two locations are not significantly different.
Test Mackenzie and Vanderhoof.

	Mackenzie	Vanderhoof	Total
≥10 cm capping	157 (143)	129 (143)	256
Other acceptable	29 (41.5)	54 (41.5)	83
Unacceptable	14 (15.5)	17 (15.5)	31
Total	200	200	400

Calculated Chi^2 = 10.562 Test Chi^2 = 12.592 at 0.05
Accept H_o of independence.
These two locations were not significantly different.
Test Dawson Creek and Vanderhoof.

	Dawson Creek	Vanderhoof	Total
≥10 cm capping	175 (150.5)	129 (153.5)	304
Other acceptable	11 (32)	54 (33)	65
Unacceptable	10 (13.5)	17 (13.5)	27
Total	196	200	396

Calculated Chi^2 = 36.858 Test Chi^2 = 12.592 at 0.05
Reject H_o of independence.
There is a significant site difference between Dawson Creek and Vanderhoof.

3. *Bräcke mounder*

	Fort St. John	Dawson Creek	Mackenzie	Total
≥10 cm capping	14 (47)	82 (42)	40 (47)	136
Other acceptable	143 (115)	77 (105)	115 (115)	335
Unacceptable	63 (58)	41 (53)	65 (58)	169
Total	220	200	220	640

Calculated Chi^2 = 80.585 Test Chi^2 = 9.488 at 0.05
Reject H_o of independence.
There is a significant location difference.
Tect Dawson Creek and Mackenzie.

	Dawson Creek	Mackenzie	Total
≥10 cm capping	82 (58)	40 (64)	122
Other acceptable	77 (91.5)	115 (100.5)	192
Unacceptable	41 (50.5)	65 (55.5)	106
Total	200	220	420

Calculated $Chi^2 = 26.734$ Test $Chi^2 = 9.488$ at 0.05
Reject H_o of independence.
Test Fort St. John and Mackenzie.

	Fort St. John	Mackenzie	Total
>10 cm capping	14 (27)	40 (27)	54
Other acceptable	143 (129)	115 (129)	258
Unacceptable	63 (64)	65 (64)	128
Total	220	220	440

Calculated $Chi^2 = 15.588$ Test $Chi^2 = 9.488$ at 0.05
Reject H_o of independence.
There is a significant difference between all three locations when capping depth is considered

Comparison of machines by location

1. *Fort St. John*

	Sinkkilä	Ministry mounder	Bräcke mounder	Total
≥10 cm capping	43 (58.5)	124 (58.5)	14 (64)	181
Other acceptable	121 (96)	34 (96)	143 (106)	298
Unacceptable	36 (45.5)	42 (45.5)	63 (50)	141
Total	200	200	220	620

Calculated $Chi^2 = 181.608$ Test $Chi^2 = 9.488$ at 0.05
Reject H_o of independence.
When depth of mineral capping is considered, there is a significant difference between all three machines at Fort St. John, with the Ministry mounder having the greatest number of mounds greater than 10 cm capping, and the Bräcke mounder the least.

2. *Dawson Creek*

	Sinkkilä	Ministry mounder	Bräcke mounder	Total
≥10 cm capping	105 (121.5)	175 (119)	82 (121.5)	362
Other acceptable	54 (48)	11 (46)	77 (48)	142
Unacceptable	41 (31)	10 (30)	41 (31)	92
Total	200	196	200	596

Calculated $Chi^2 = 106.121$ Test $Chi^2 = 9.488$ at 0.05
Reject H_o of independence.
When mineral soil capping depth is considered, there are significant differences between the machines.
When the Bräcke mounder and Sinkkilä are compared alone:

	Sinkkilä	Bräcke mounder	Total
≥10 cm capping	105 (93.5)	82 (93.5)	187
Other acceptable	54 (65.5)	77 (65.5)	131
Unacceptable	41 (41)	41 (41)	82
Total	200	200	400

Calculated $Chi^2 = 6.866$ Test $Chi^2 = 9.488$ at 0.05
Accept H_o of independence.

3. *Mackenzie*

	Sinkkilä	Ministry mounder	Bräcke mounder	Total
≥10 cm capping	16 (104)	157 (52)	40 (57)	213
Other acceptable	161 (149)	29 (74)	115 (82)	305
Unacceptable	223 (147)	14 (74)	65 (81)	302
Total	400	200	220	820

Calculated $Chi^2 = 424.264$ Test $Chi^2 = 9.488$ at 0.05
Reject H_o of independence.
Clearly from the data there is a significant machine effect for all three machines.

APPENDIX 3. Comparison of left and right shovels—Bräcke mounder. Contingency table analysis.

Fort St. John

	Left shovel	Right shovel	Total
Capping > 6 cm	30 (35)	40 (35)	70
Other acceptable	46 (43.5)	41 (43.5)	87
Unacceptable	34 (31.5)	29 (31.5)	63
Total	110	110	220

Calculated $Chi^2 = 2.112$ Test $Chi^2 = 5.991$ at 0.05
Accept H_o of independence.
There is no significant difference between left and right shovels on the Bräcke mounder at Fort St. John.

Dawson Creek

	Left shovel	Right shovel	Total
Capping > 6 cm	68 (70.5)	73 (70.5)	141
Other acceptable	11 (9)	7 (9)	18
Unacceptable	21 (20.5)	20 (20.5)	41
Total	100	100	200

Calculated $Chi^2 = 1.114$ Test $Chi^2 = 5.991$ at 0.05
Accept H_o of independence.
There is no significant difference between left and right shovels on the Bräcke mounder at Dawson Creek.

Mackenzie

	Left shovel	Right shovel	Total
Capping > 6 cm	35 (41)	47 (41)	82
Other acceptable	44 (36.5)	29 (36.5)	73
Unacceptable	31 (32.5)	34 (32.5)	65
Total	110	110	220

Calculated $Chi^2 = 4.976$ Test $Chi^2 = 5.991$ at 0.05
Accept H_o of independence.
There is no significant difference between left and right shovel on the Bräcke mounder at Mackenzie.